

# THE NASA APPROACH TO REALIZE A SENSOR ENHANCED-SYNTHETIC VISION SYSTEM (SE-SVS)

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## Background

Historically, several programs have been implemented to understand the role sensors and sensor systems play to improve airline traffic flow in all weather conditions. Magic Window, the FAA SVS program and several independent commercial carrier programs including the Boeing Company's Enhanced Situational Awareness System (ESAS) (1992).

In 1992, a benchmark year for this study, there was little confidence in a GPS-based aircraft navigation system. The technology for a viable data-based map for use by a crew was not developed; its viability was unclear. Even TCAS, Traffic Alert and Collision Avoidance System, was causing concern at densely populated airports. Strategies developed in that time period were dependent upon onboard sensors alone to satisfy the requirements. Sensors such as CCD cameras; FLIR; millimeter wave, K-band, X-band radar; and UV were all reviewed. All were found limiting as stand-alone sensors or in combinations. At that time, the conclusions reached were that a single sensor could not satisfy the stated operational requirements to insure category I-III certification; two sensors also could not meet the stated operational requirements. An issue that often surfaced which is still of concern is the image quality required to allow the crew to safely land an aircraft under all weather conditions.

The image quality degrades from CCD cameras to infrared, to passive millimeter wave and radar derived "imagery". Imagery derived from W-band has somewhat improved resolution over K- and X-band radar. Sensor performance in adverse weather, however, tends to degrade as the operating frequency increases. Clearly cost-effective solutions for achieving the desired capabilities were not available based on 1990 technology. Today with GPS capabilities demonstrated, navigation is no

longer an issue. Stored data base maps/airport scenes are emerging as sufficient to land an aircraft under a variety of weather conditions. TCAS and ground-based radar/transponder systems can provide most cooperative object detections for reduced runway incursions. Digital data links can provide much needed cockpit information. However, there still exists a need by the cockpit crews for confirmation of runway location and detection of non-responding objects on or near the active runway. This is a major role for an onboard Enhanced Vision Systems (EVS).

In May 1998 the National Aeronautics and Space Administration (NASA) developed a program to support the aviation community and safe air travel through the creation of the Aviation Safety Program (AvSP) [1]. The goal of this program is to contribute towards the reduction of the aviation fatal accident rate by 80% over the next ten years. Because of the numerous causes and factors that contribute to the variety of accidents and incidents that occur each year, NASA has identified and is funding a wide variety of projects in order to achieve this goal. One such project is the Synthetic Vision Systems (SVS) element of the AvSP that is investigating the primary, non-mechanical cause of accidents; specifically, pilot errors caused by a lack of vision or visual cues, including lack of situational awareness. Additionally, with a robust SVS, pilots will be able to conduct Visual Flight Rule (VFR) operations, even when actual visual ranges preclude these operations, thus, decreasing operating costs and maintaining and improving safety.

The operational goal for SVS is to provide operators the safety and operational benefits of VFR-like capabilities during Instrument Meteorological Conditions (IMC) [2]. The SVS concept, as originally conceived, is based upon use

of the Global Positioning System (GPS) and database representations of terrain, obstacles, and high-resolution inserts of the airport layout, integrated with available Communication, Navigation and Surveillance (CNS) information. While GPS and databases can provide the primary framework for an operational system, many in the aviation community believe that independent integrity monitors for both surveillance and navigational functions will be required to meet certification and safety requirements. The SVS program intends to use Traffic Collision Avoidance System (TCAS), Automatic Detection Surveillance - Broadcast (ADS-B), and Airport Surface Surveillance Radar (ASSR) for surveillance purposes. While these systems can provide integrity assurance to some degree, the systems rely upon cooperation and communication of information to maintain safe operations. Many in the aviation industry believe that this type of integrity assurance partially fulfills rigorous certification requirements.

Airline pilots and others in the avionics community continue to promote onboard sensors (either modified or new) as a requirement to augment the projected sensor suites including CNS and Terrain data bases. NASA accepted these recommendations. In response, NASA developed three specific programs including: air-to-air traffic surveillance, a runway incursion monitor, and a minimal confirmation of database registration (navigational position confirmation). All of these activities rely on in situ sensors. The goal of the Sensor Enhanced-Synthetic Vision System (SE-SVS) program is to provide improved pilot situational awareness during all phases of flight and in all weather conditions. Candidate SVS sensor concepts developed early in the program have been characterized and documented in a report [3]. It discusses issues associated with the selection of technologies and components as of July 2001. Under NASA contract, the economic impact of SVS capabilities to provide input to the NASA SVS Concept of Operations (CONOPS) Program was estimated and reported by the Logistics Management Institute [4].

## **SV Sensor Functions**

At the inception of the program, several sub-products were planned for demonstration that would serve as critical functions for the system. These critical functions include air-to-air object detection (Non-Cooperative Aircraft Tracking), air-to-ground object detection (Runway Incursion Detection and CFIT-Avoidance), and ground-to-ground object detection (Runway Operations). These functions integrated and built upon a modified airborne Doppler radar and FLIR technologies that were studied under NASA's High Speed Research Program (HSR) [5]. The association and blending of tracks from multiple targets and sources would ultimately evolve into a capability for Multi-Target Tracking (MTT), which with automatic detection could result in a totally automated system for object detection and subsequent mitigation of threats by the cockpit. For terrain feature extraction, the Sensor Enhanced-Synthetic Vision System (SE-SVS) becomes a blending of non-expectation driven data base integrity monitoring information with expectation-driven information derived by sensors to provide runway confirmation and identification of missing features in real-time scenarios.

### ***Sensor Suite***

In the sensor enhanced portion of the SE-SVS program, the focus of the research and development is to determine the feasibility of adapting a modified X-band Airborne Doppler Radar [6] (Wx Radar) and state of the art FLIR sensors [7]. This approach was adopted after an assessment was made of the optimal benefit the NASA program could provide to industry stakeholders. Subsequently, the rationale for taking this approach is discussed.

Several steps were taken prior to selection of this approach. First, those sensor technologies that potentially played a role in satisfying the five functions in the five phases of flight were identified. Three sensor systems were considered: 1) Visual Imagery (CCD cameras); 2) Passive infrared (short-mid-long wave); 3) Radar (X-K-W band). The status of available sensor technologies was estimated. Figure 1 summarizes our assessment; Lidar was excluded since we felt the technology, although having significant promise, was considered far from a technology readiness

level for near term applications. For the sake of completeness, Lidar can be inserted in all boxes with radar with the exception of cases under severe fog and/or other adverse weather conditions. Also, a question mark was placed with radar since it is not

clear in both taxi and takeoff phases of flight whether active radar on multiple aircraft close to the runway would be allowed to radiate due to potential EM interference problems. This is a consideration that must be addressed.

	TAXI	TAKEOFF	CRUISE	APPROACH	ROLLOUT & GROUND HANDLING
<b>RUNWAY INCURSION AVOIDANCE</b>	<b>VISUAL IR RADAR?</b>	<b>VISUAL IR RADAR</b>		<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR?</b>
<b>AIR-to-AIR OBJECT DETECTION</b>		<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	
<b>DATA BASE REGISTRATION CONFIRMATION</b>	<b>VISUAL IR RADAR?</b>		<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR?</b>
<b>TERRAIN AVOIDANCE</b>		<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	
<b>WX/WS</b>		<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	<b>VISUAL IR RADAR</b>	

**Figure 1. Enhanced Vision-Synthetic Vision Sensor [EV-SVS] Functions versus Phases of Flight Applicable Sensor Technologies**

The technologies listed in Figure 1 were assessed according to their adaptability in improving vision performance for the five functions: 1) Runway Incursion Avoidance; 2) Air-to-Air Object Detection; 3) Data Base Registration Confirmation; 4) Terrain Avoidance; 5) Weather (Wx/Ws). Also, we considered installation requirements for the retrofit market that would require none to major modifications. In addition, we evaluated the equipment readiness of the sensors based upon existing products. One of four subjective ratings was given to each category including: High/Medium/Low/Not Applicable. Figure 2 is a summary of the results. One objective adopted was to “fill-in” the transponder row with a rating of “high”. A solution appeared to be a fusion of short and long wave infrared imagery, with a modified X-band radar. The challenge for a research program then becomes resolving whether data base registration confirmation can be achieved in practice for the X-band radar.

From a program development standpoint, we “brain-stormed” a potential insertion approach for

new sensor systems into the retrofit fleet market (Figure 3). Two different types of systems were envisioned as part of the insertion approach. 1) combinations of sensors that provided a stand-alone capability for CAT I-III conditions; 2) a combination of sensors fused with the SVS system that fully optimized a capability for CAT I-III conditions. For stand-alone sensor combinations there appear to be two viable combinations: 1) W-band radar with short and long wave infrared. This could represent a first-to-market approach by industry and requires demonstration of new sensor technology, namely the applicability of millimeter wave radar. As the SVS system reaches its maturity, the systems can be fused to provide a full-up ES-SVS system (System A). 2) Visible (CCD) imagery, with X-band radar derived imagery for object detection and runway detection and CFIT avoidance with short and long wave infrared. As the SVS system reaches its maturity, the systems can be fused to provide a full-up EV-SVS system (System B).

SENSOR	Runway Incursion Avoidance			Air-to-Air Object Detection			Data Base Registration Confirmation			Terrain Avoidance			Wx/WS	Installation Issues	Equipment Readiness
	C	F	Wx	C	F	Wx	C	F	Wx	C	F	Wx			
Visual	△		□	△			△		□	△		□	●	△	△
Lidar	△	□	□	●			△	□	□	△		□	□	□	□
IR (s/m)	△	□	□	●			△	□	□	●			□	●	●
IR (l)	△	□	□	●			△	□	□	△		●	□	●	●
MMW w	△	△	□	●	●	□	△	△	●	△	●	□		□	●
MMW ka	△	△	●	●	●	●	△	△	●	△	△	●		□	●
Modified Wx Radar	●	●	●	△	△	△	●	●	●	△	△	△	△	△	●
Transponders	△	△	△	△	△	△							△	△	△
OTHER															
△ –High      ● –Medium      □ –Low      C = Clear      F = Fog      Wx = Weather															

Figure 2. Assessment of Sensor Technologies for Applications to ES-SVS Sensor Functions

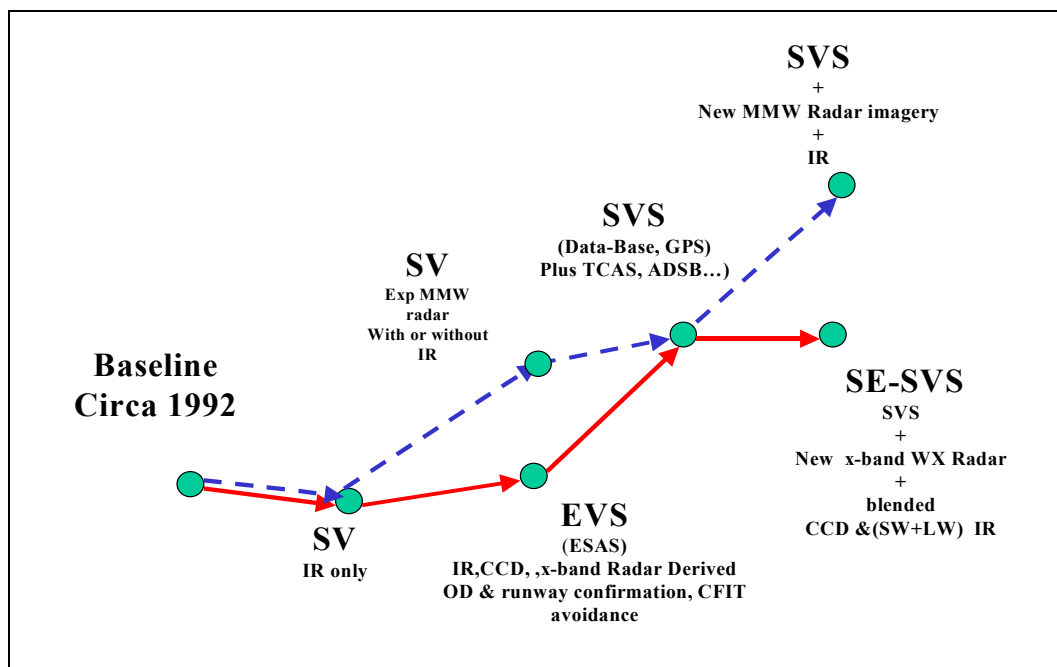


Figure 3. Paths to SE-SVS Full Capability

### ***Other Factors and Considerations***

Other factors and considerations were used to decide on this approach. The baseline performance from which the sensors are compared in Figure 3 is visual daylight in clear weather. It is clear that visual imagery (human vision and/or CCD camera) plays a vital part in performing every function for each phase of flight. Infrared imagery (FLIR) represents the other imaging sensor capability. FLIR is expected to enhance the situational awareness in each flight phase. It offers a major improvement in nighttime vision. Even though the FLIR is currently non-responsive to color, it is felt that the improvement in ground operations (especially at night) makes enabling this sensor capability important. In hazardous weather, haze, and some fog conditions, the FLIR (short wave or extended mid-wave) can increase the visible detection range of the approach and runway edge lights significantly. The taxi and rollout & ground handling flight phases benefit from this improvement in nighttime vision. During this phase of flight, the need for an onboard infrared sensor is definitely required.

SVS allows operation in lower ceiling minimums and therefore increases the need for object detection requirements under hazardous weather conditions. Onboard object detection in the taxi, rollout and ground flight phases will be magnified and will require significant improvements in the sensors' ability to extend the range and increase angular range resolution. Due to EM interference, the use of active sensors could be restricted or possibly disallowed. There may be a need to request a greater portion of the EM spectrum from the FCC to make use of spread spectrum techniques. This puts a heavy burden on infrared imagery alone.

Under severe fog conditions, infrared imagery is limited in its penetration, although the cutoff conditions are not well understood. There has been a continuing debate concerning which band of IR offers the best performance in fog and in clouds. In dense fog conditions neither band is probably adequate. During these severe conditions the modified X-band radar appears to be the only sensor to insure an "all weather" capability for Runway Incursion Avoidance. Further, during this

interval the radar can conduct Data-base Registration Confirmation. However, the benefits offered by the addition of the FLIR to the SVS system far outweigh the small percentage of time that the FLIR would be blind. X-band radar is not a substitute for the infrared imagery but fits a need when fog blinds the vision of the crew.

Radar derived imagery regardless of its source, either K- or W-band, does not have the same quality as an infrared camera. The "imagery" derived from a millimeter wave radar (both W and K bands) has limitations in image quality and in distorted perspective. The radars, which are currently in use translate angle and range information into a perspective presentation. As height information isn't normally provided, all objects appear the same height. Further, as the perspective radar image is generated, the foreground appears as larger block returns, which tends to clutter the display. The pie-shaped radar return causes this cluttered display. When the perspective presentation is created the close in radar returns become bigger chunks. As technology further develops, some of these issues should be resolved.

There is also concern with performance for W-band radar in severe weather, particularly heavy rain. Also the need to find space for an additional antenna system for retrofit aircraft is not trivial. Shorter wavelengths require modifications to the existing aircraft radome. These factors could be significant cost drivers for the retrofit market.

Although there is greater availability of K-band power sources that can produce better range detection than with W-band radar, image quality remains a greater issue. However, the improved resolution from the K band over X band may be sufficient to more accurately resolve and position icons than the X-band radar. K band, with its improved angular resolution over the X-band radar, can be useful not as an imaging sensor but to collect angle and range data on objects for performing the air-to-ground and perhaps the ground-to-ground functions.

The X-band weather radar has appeal because it exists on the aircraft. Efforts to generate useful imaging for the approach phase of flight have been unsuccessful. X band has been used for decades to detect objects, including aircraft. Consideration of X-band radar for object detection and database

registration confirmation in conjunction with an imaging sensor such as infrared and CCD cameras begins to meet the totality of requirements. This combination, augmenting the database-driven SVS, has become the core of the NASA EV portion of the EV-SVS program. The installation challenges are restricted to the FLIR system since the weather radar is already installed. Research is needed to improve the angular resolution to satisfactorily accomplish "Runway Incursion Avoidance" and "Data Base Registration Confirmation." As stated earlier, if the research-based X-band radar system cannot satisfy angular resolution requirements, then millimeter radar (particularly K-band systems) may be required to collect position information.

Details of the characteristics of the X-band radar and Infrared imaging sensors being used by NASA in the flight test program are briefly described in this paper and are fully covered in [6, 7].

## **Sensor Description**

The NASA aircraft EVS configuration is composed of a visual (CCD) camera, a short-wave FLIR, a long-wave FLIR and a modified X-band radar. Inputs from externally-generated sensor sources are piped directly to the SVS processors. The resulting information from these processed SVS data sources is available for display and is recorded for later analysis. The imaging sensors (i.e. the two FLIR imaging sensors and the CCD camera) are housed in an enclosure that is installed on a 757 forward equipment bay access door. This sensor location is not considered optimal from an operational perspective but is configured in this manner to provide rapid swapping of the cameras and housing with the original equipment bay access door when the aircraft is not in the test configuration.

### ***Research Radar***

The experimental X-band weather radar used for the data collection phase differed from the conventional commercial weather radar in a number of ways. Actually, this radar was an outgrowth of the X-band system used by the HSR program.

A brief system description is contained in the following section. This radar, as well as the HSR

radar, incorporated the capability of frequency stepping from pulse to pulse. By combining the returning stepped frequency signals it is possible to demonstrate a range resolution improvement over that resolution expected from the actual transmitted pulse width. It was hoped that useful experimental data could be collected for the EVS studies with this available radar while piggy backed to the SVS flight test program. The aircraft-mounted experimental radar demonstrated during ground tests that the pulse compression technique did indeed improve the range resolution by, at least, an order of magnitude. Problems normally expected from an all-linear pulse compression system of this type were cleverly sidestepped by employing a sampled data system. Most notably, the associated delay line amplitude loss and phase shift error were avoided. The sampled data systems can store data in such a way that entire ensembles can be processed simultaneously, a very powerful advantage because normally generated range side-lobes need not be directly exposed. In the real world where infinite bandwidth signals and finite width samplers do not exist, anomalies occur. The experimental radar results demonstrated that these newly compressed signal representations could appear to wrap around within a single range gate. In addition, the broadening in time of the returning target samples cause straddling of two range gates simultaneously. This signal straddling of two or more sample intervals gives the appearance of separate ghost objects present in adjacent range gates.

The radar target data taken during the flight tests were recorded for study and analysis. These data are stored as in phase (I) and quadrature (Q) voltages for each received frequency.

## **Experimental Radar Description**

A modified Rockwell-Collins radar was installed on the NASA 757 aircraft in support of Turbulence detection and Enhanced Vision Systems elements of the Aviation Safety Program (see Table 1). This radar consisted of a standard PACER-CRAG radar developed for the Air Force and modified in three areas: recorder interface, control and DSP software, and agile frequency source. In addition, the antenna and pedestal were modified to facilitate changes in antenna

polarization and beam sharpening utilizing a sum/difference beam technique.

**Table 1. Rockwell/Collins Research Radar**

Parameter	Value for Rockwell/Collins Research Radar
Transmit Power	135W
Minimum Discernable Signal	-124 dBm

A fiber optic interface was added to the radar to transmit raw I/Q data for recording. This data stream contains four parts: 1) An aircraft header containing aircraft parameters as supplied to the radar through ARINC 429 busses; 2) An I/Q header containing radar setup parameters; 3) Digitized I/Q data; 4) Gain factors applied to each range bin. DSP software was enhanced to support the research capabilities of the radar including data collection, reconfiguration, and antenna aperture control (beam sharpening). A control menu was provided via the RS-232 port for selection/setting of parameters. A sequence of up to eight programmed antenna azimuth scans may be programmed. Any of the eight scans may be programmed with parameters from a table or set to the preprogrammed SVS mode [6]. In addition, the first scan may be configured to be a weather scan, providing conventional weather displays to the pilots.

The agile frequency source makes possible the use of a frequency stepped transmit waveform, an essential component of the SVS mode. In the SVS mode summarized in Table 1 of [6], the transmit frequency is decreased by 1.00 MHz with each pulse pair during the set of pulses that comprise one dwell. In the SVS mode, the radar uses 64 pulses for collecting data for one "dwell." Two pulses per frequency are transmitted and data is collected first in the sum beam antenna configuration and then in the difference beam configuration. For an ensemble of 16 frequencies, 32 pulses are required. The 64-pulse dwell contains two complete 16-frequency sets.

### ***Radar Installation on NASA 757***

The radar is installed in the NASA 757 aircraft in a dual R/T installation. The second R/T is a

standard Rockwell-Collins weather radar so a display from a certified unit is always available to the pilot. The research radar does provide the same display although the update rate may be slower due to the interleaved antenna scans dedicated to research data collection. The pilot in the research radar controls parameters for the WX scan since they are in the standard radar, although in the 757 installation the source of tilt and gain information is the WXI-711 installed in the cockpit. The research radar as installed in the NASA 757 includes the following interfaces:

- 1) ARINC 429 avionics busses for radio altitude, GPS, air data computer, and inertial navigation system data; 2) ARINC 429-control bus; 3) Discrete data such as weight on wheels; 4) ARINC 453 outputs to cockpit and Station 18 displays; 5) Data line to record/display system in Station 18 (optical fiber); and 6) Power and power control lines.

### ***Signal Processing System for the Experimental Radar***

The processing control system in Station 18 of the 757 consists of the following components: 1) Record computer -- a 600-MHz dual Pentium industrial computer for recording radar I/Q data, 453 (display) data, and aircraft state information from ARINC 429 busses. This computer contains a DSP board with optical receiver to receive data stream from radar and replicate it into two streams, one for storage on the hard drive and a second for passing data directly to DSP boards on the processing computer via high speed serial connection. 2) Processing computer -- an industrial computer similar to the record computer configured with two dual processor DSP boards for real-time signal processing of the data from the radar.

Software development for the real-time processing computer requires a data stream from the radar or simulated replica thereof. To satisfy this requirement, a development computer was configured like the aircraft computer but with the addition of one additional DSP board. Software was written to read recorded data from a file on CD or the computer's hard drive and pass the data to the third DSP board for output of a high speed serial connection as is done in the Record Computer, the source of data for the processing computer on the

NASA 757. Flight software was then developed as a second application with components running on the Pentium processors and the first two DSP boards. This development environment simulated that of the aircraft, especially when external ARINC 429 buses were generated to simulate the avionics and processed data busses available on the aircraft (not needed for all applications of the research radar). Applications developed in this environment may be taken to the aircraft via CD with a high degree of confidence that they will work in the flight environment.

### ***Algorithm Implementation***

A basic pulse compression algorithm was implemented for processing signal returns from the frequency stepped-pulse sequence waveform transmitted by the radar. The processing consisted of the following: 1) Velocity compensation -- a phase adjustment applied to the I/Q data to compensate for the difference in range between transmit pulses due to aircraft movement and the Doppler shift associated with the relative radar-target movement. 2) FFT -- for each of the 42 range bins, convert the I/Q data from pulses at each of 16 transmit frequencies into a time series corresponding to the return from a compressed transmit pulse. 3) Beam sharpening -- the collection of sum beam pulses and difference beam pulses are processed separately and then combined to effectively sharpen the transmit beam. (Code for this was implemented, but a malfunction in the antenna polarization rotation mechanism for the antenna on the aircraft prevented the collection of data that could be enhanced using this technique.)

Software was developed on the development system for porting to the flight system. The development system proved useful for the examination of flight data and for the experimentation with algorithms and parameters to optimize algorithm performance. However, since the development system code relied on the presence of relatively uncommon DSP boards, the DSP code was ported to the Pentium processor to produce a standalone version described in Appendix D of [6].

### ***Observations***

The implementation of the algorithms identified above was first applied to test data acquired with the aircraft located at the end of an unused runway and facing so that the runway was centered in the forward field of view of the radar. Radar targets (corner reflectors) were located at various distances along the runway. In some runs, the targets were at fixed locations and in other runs the targets were mounted in moving vehicles. The processing output for known target positions was useful in tweaking the algorithms to minimize effects such as range bin ambiguity (the indication of target location within several adjacent range bins). Finally, the processing was applied to scene data taken at Dallas-Fort Worth to evaluate the performance on a complex scene from a moving platform.

Examination of results from the application of the algorithm to runway targets indicated that the pulse compression was capable of locating a target within a range bin. The processing described above produces 16 fine range bins in each standard or coarse range bin. Since the I/Q sample rate was 1  $\mu$ s, coarse range bins were 150 m, and the fine bins produced by the resolution enhancement processing were 9.375 m. The processing was successful in identifying the fine range bin corresponding to the target location and concentrating most of the energy to that fine bin. However, two negative effects were noted: 1) Energy from any target is spread over more than one coarse range bin by the bandwidth limited filtering of the receiver. The pulse compression processing does concentrate the return from a point target to a single fine bin within the coarse bin where the energy was received. However, since the energy from a single target is spread over several coarse bins, the processing will produce a concentration of energy in the  $n$ th fine bin for all coarse bins containing energy from this target, introducing multiple responses to a target when only one location is real. 2) The pulse compression processing concentrates the energy from a target in the fine bin corresponding to the actual location of the target within a coarse bin. However, this concentration is not complete. Some energy is distributed among the remaining fine bins so that a strong target will mask smaller targets located in the same coarse bin.

Further results on the performance of the research radar for object detection will be presented at the conference.

### ***Infrared Imaging***

While the radar can fulfill many applications for transport aircraft, the use of FLIRs and low-light visible-band cameras have a role to perform and a niche that cannot otherwise be filled. Broad requirements include:

1) Runway Incursion Monitor - Recent flight tests (NASA HSR Program) demonstrated the ability to perform autonomous, in-flight, air traffic, object detection using optical systems (visible and FLIR imagery). Extending this capability to Runway Incursion is an area of interest for EVS and will support the SVS concept. 2) Situational Awareness - Whether directly shown to a pilot as a sensor image or as part of the synthetic paradigm (iconic representation), FLIR imagery can provide confirmation of terrain features, runway/taxiway locations, and other aircraft. The natural horizon must be revealed in poor visibility conditions. 3) Night/Low-Visibility Taxi - Among the primary uses, FLIR can provide day-like imagery that is presented to the pilot directly or as iconic confirmation of scene features. Image processing algorithms can be applied to the raw imagery to extract runway/taxiway lights, edges, and intersections. Parked aircraft/vehicles or ground personnel will be readily visible, as well as determining if "clear runway for departure" exists.

In the following sections, a description of the three-camera FLIR system developed for this program, integrated into the 757 and flight tested will be summarized. The FLIR camera system is still evolving and will undergo major flight-testing in the winter/spring of 2003.

### ***Camera System***

The cameras selected for inclusion into the FLIR Pod represented the state-of-the-art infrared technology at the time of the design. The visible camera used is a Bowtech BP-L#C-II CCD system covering the visible band (0.4-0.78 microns).

The Merlin-NIR is a high-performance Near-Infrared (NIR) camera system, based on the ISC9809 Focal Plane Array, using uncooled Indium

Gallium Arsenide (InGaAs) detectors. InGaAs is the best detector material available for sensing energy in the 0.9 to 1.68  $\mu\text{m}$  wideband. The focal plane array (FPA) size is 320X256, with 30X30 micron pixels. It has high reliability (>14,000 hrs MTBF), low life cycle cost, no cryogenic cooler, no chopper, no scanner, and excellent spatial resolution. The Thermal Imager is an advanced military hardware device. It has an advanced 327X245 uncooled bolometer focal plane array. The detector is optimized for the 8-14  $\mu\text{m}$ -spectral range. The sensitivity of the LTC500 is comparable to that of many first generation photoconductive systems, but requires neither a scanner, cryogenic cooler, or mechanical chopper. There are no moving parts during normal operation. The MTBF is greater than 14,000 hours. Detailed specifications for the cameras are provided in [7] and are not repeated here.

### ***System Installation on 757***

Aircraft engineers and technicians installed the three-camera system on the NASA 757. The system's integrated hatch door design allowed easy installation for flight tests. Two cable assemblies provide video, communication, control, and power to the camera system. The two cables have MIL-STD connectors (D38999/26WH35SN and MS24266R22B19PN) to connect the pod to the aircraft system at receiving connectors on the aircraft bulkhead.

The control center for the FLIR Pod is located at a research station at Palette 18 on the NASA 757. The analog video signal coming from each camera is routed to Matrox Genesis frame grabber boards and through time code generators to encode UTC time before they are recorded onto SVHS tapes and displayed on monitors at Palette 18.

### ***PHF Observations***

The NASA 757 conducted a FLIR evening research flight (R-238) on Wednesday, May 15, 2002 in support of the Enhanced Vision Systems (EVS) component of the Synthetic Vision Systems Project. The flight included three dusk approaches and four night approaches at Newport News / Williamsburg International Airport (PHF). FLIR video data was recorded for all seven approaches

with various runway approach lighting and camera intensity and gain settings. The FLIR data collected will be very useful in supporting continued image enhancement activities. In addition, a test of the Merlin upscan converter (RS-170 to RS-343) was performed at NASA Langley after the 757 landed. The new RS-343 signal path evaluated on the ground showed significant improvements in providing a better dynamic range for contrast and brightness control of the image on the HUD. The other significant improvement afforded by RS-343 was that the runway, taxiway, and terrain features were more conformal than with the RS-170 implementation.

Preliminary results from the observations at PHF are discussed in [7] and will be discussed further at the conference.

## Summary

A combination of data from X-band radar, visual, and IR cameras can be merged to provide the pilot (on head-up or head-down displays) situational awareness in adverse weather and darkness for and during airport approach, approach and landing guidance, runway incursions/runway object detection, and taxiing. On smaller aircraft (commuter, business jets, and GA) where the proposed radar technology cannot be installed, FLIRs and low-light visible cameras are likely the only sensor candidates that perform these functions.

AvSP-EVS Radar (FY 2000 DFW) progressed significantly because of the NASA program. The AvSP Research Radar was integrated onto the NASA 757, which provided basic safety of flight operations and SVS and WxAP research simultaneously. Testing of new radar hardware with the research radar has allowed Collins to introduce a new generation of radar based on this design. Twenty-four hours of Runway Incursion Monitoring (RIM) data were collected during three weeks of approach, landing, takeoff, and taxi operations at DFW. As a result of the data collected and results obtained from the research radar, Collins has proposed RIM as a new commercial radar (INSITE Flight Tests FY 2003). "Touch and Go" FLIR flight-testing at PHF (FY 2002) appear positive indicating that both sensor systems are performing to the expected requirements. Our future plans are to collect Terrain Awareness data

during EGE deployment during Initial SVS Integrated Technology Evaluation (INSITE) Flight Tests in FY 2003. A primary objective is to investigate CFIT avoidance applications with the combined research radar and infrared camera system.

While the radar can fulfill many applications for transport aircraft, the use of FLIRs and low-light visible-band cameras have a role to perform and a niche that cannot otherwise be filled for the various functions identified in the program. For example, NASA flight tests under the High Speed Research Program demonstrated the ability to perform autonomous, in-flight, air traffic, object detection using radar and optical systems (visible and FLIR imagery). Extending this capability to Runway Incursion is an area of interest for EVS and will support the SVS concept. Whether directly shown to a pilot as a sensor image or as part of the synthetic paradigm (iconic representation), FLIR imagery can provide confirmation of terrain features, runway/taxiway locations, and other aircraft. The natural horizon must be revealed in poor visibility conditions. Among the primary uses, FLIR can provide day-like imagery that is presented to the pilot directly or as iconic confirmation of scene features. Image processing algorithms can be applied to the raw imagery to extract runway/taxiway lights, edges, and intersections. Parked aircraft/vehicles or ground personnel will be readily visible, as well as determining if clear runway conditions exist.

Even though sensors at SWIR (InGaAs) and LWIR (Microbolometer) are considered by some as optimum technologies for the detection of runway lights and for fog/nighttime visibility penetration, there will be times when the fog and cloud conditions are such that any FLIR will become temporarily blind. It is during these times that the X-band radar will provide real-time position information on detected objects and will provide valuable runway position confirmation data to the SVS while on the approach phase of flight.

As the aviation industry has continued to strive for safer and more efficient operation, NASA and industry have been, over the years, fine tuning technology for the time when safe all-weather operation can be achieved for all flight conditions, cost effectively. The NASA SE-SVS approach is

bringing that goal closer. This approach offers a unique capability and should be available for the next new aircraft development program. In the interim, the SE portion of the program will contribute to the retrofit market by bringing improved situational awareness at a minimum cost. Many of the early starts, which ended on the cutting room floor, provided the incentive to improve system capability by including technologies that in 1992 were not mature. Remaining questions today include such things as how much more capability is actually needed. NASA, industry, and the FAA need to come together with a positive resolution. NASA, in concert with the FAA, is in a position to assess the industry configurations while working closely with the airframe manufacturers. Working together, systems should evolve that are cost effective to own and offer improved situational awareness.

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